Test of a Liquid Argon TPC in a magnetic field and investigation of high temperature superconductors in liquid argon and nitrogen

A. Badertscher, L. Knecht, M. Laffranchi, G. Natterer, A. Rubbia, Th. Strauss

Institute for Particle Physics, ETH Zurich, Switzerland

E-mail: `badertscher@phys.ethz.ch`

Abstract. Tests with cosmic ray muons of a small liquid argon time projection chamber (LAr TPC) in a magnetic field of 0.55 T are described. No effect of the magnetic field on the imaging properties were observed. In view of a future large, magnetized LAr TPC, we investigated the possibility to operate a high temperature superconducting (HTS) solenoid directly in the LAr of the detector. The critical current I_c of HTS cables in an external magnetic field was measured at liquid nitrogen and liquid argon temperatures and a small prototype HTS solenoid was built and tested.

1. Test of a LAr TPC in a magnetic field

The liquid argon time projection chamber (LAr TPC) [1] is a homogeneous 3D tracking device for charged particles with excellent - bubble chamber like - imaging properties and at the same time it is a fine grain calorimeter for fully contained particles due to the measurement of the energy loss dE/dx. The ICARUS collaboration has demonstrated the feasibility of this novel technology for large mass detectors. A 600 ton (T600) detector consisting of two identical 300 ton half-modules was built and successfully tested [2]. The detector is now installed a the Gran Sasso underground laboratory in Italy. The possibility to operate the LAr TPC in a magnetic field would add the very interesting features of determining the electric charge of particles and the momentum, also for particles leaving the chamber [3, 4, 5, 6]. The measurement of the charge, e.g., is a must for future experiments trying to measure CP violation in the leptonic sector at a neutrino factory.

An R&D program to investigate a small LAr TPC in a magnetic field was performed. The goal was to study the drift properties of free electrons in LAr in the presence of a magnetic field and to prove that the imaging capabilities are not affected. A detailed description of the experiment is given in [7] and results were published in [8, 9]. Fig. 1 is a 3D CAD drawing showing a cut through the setup with the essential components of the experiment. The scintillators on top of the magnet, in the bore hole on top of the cryostat, and at the bottom of the magnet were used to trigger on cosmic ray muons. The LAr cryostat was inserted into the recycled SINDRUM I magnet from PSI[1] which allowed to test the chamber in a maximal field of 0.55 T.

[1] Paul Scherrer Institute, CH-5232 Villigen, Switzerland

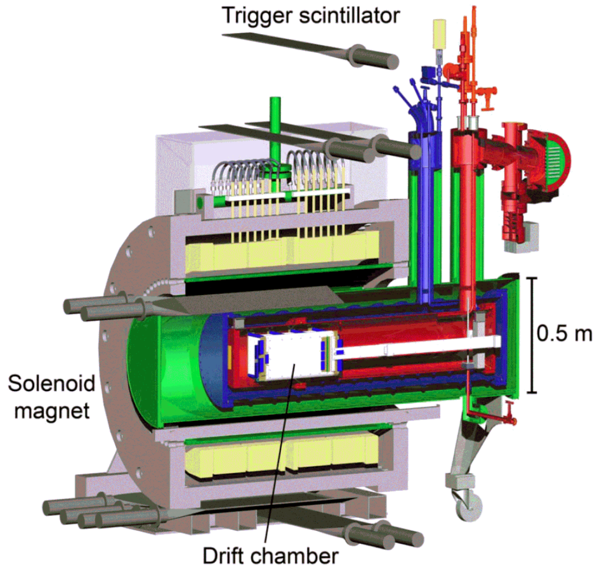

Figure 1. Global view of the experiment.

The cryostat consists of three concentrical stainless steel cylinders: the innermost cylinder contains the purified LAr with the drift chamber, the second cylinder is a LN_2 bath kept at a pressure of 2.7 bar in order not to freeze out the LAr at about 1 bar, and the outermost cylinder is for the insulation vacuum.

The chamber has a length (along the B-field direction) of 300 mm, a height of 150 mm and a maximal drift length of 150 mm (horizontal drift field perpendicular to the B-field). The left side of Fig. 2 shows a CAD drawing into the open chamber, and and the right side is a picture of the chamber ready to slide into the cryostat. After pumping the LAr cryostat, it was filled through a purification cartridge containing activated Cu powder to remove impurities, mainly O_2, the LAr was not recirculated anymore through the cartridge after the filling.

The chamber consists of a stainless steel cathode, 27 field shaping electrodes to produce a

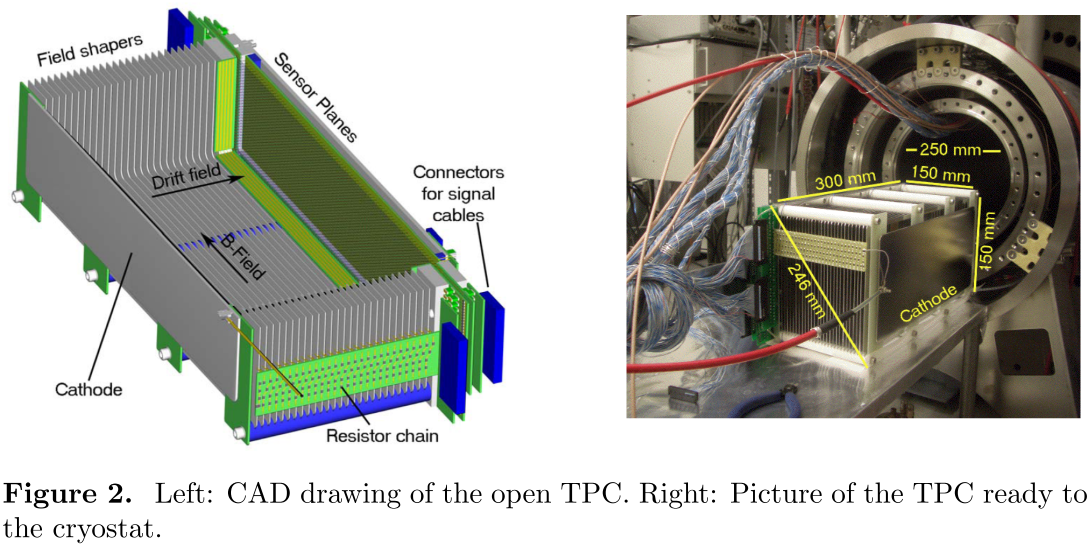

Figure 2. Left: CAD drawing of the open TPC. Right: Picture of the TPC ready to slide into the cryostat.

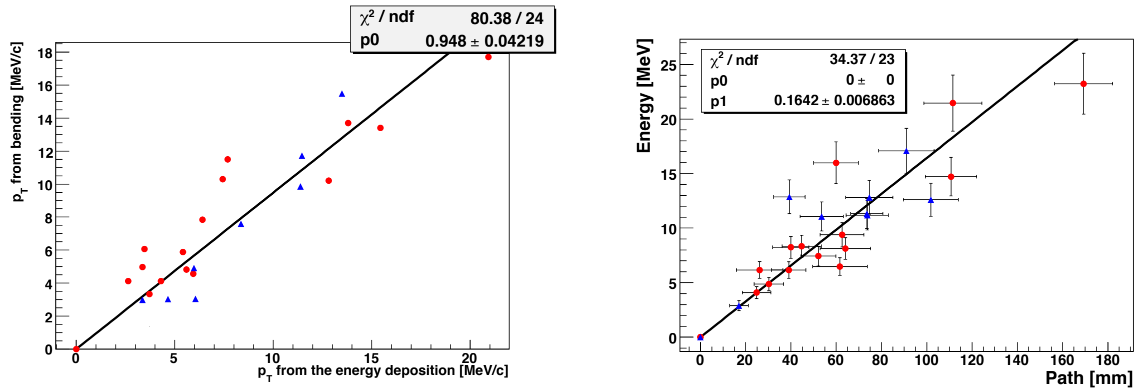

Figure 3. left: Correlation between the two momentum measurement methods for δ-electrons (circles) and decay-positrons (triangles); right: Measured energy as a function of the reconstructed path length of the δ-electrons (circles) and the decay-positrons (triangles).

homogeneous drift field and 3 sensor planes. The first two detector planes (induction planes) are wire chambers with 100 μm wires oriented at $\pm 60^0$ to the vertical and a pitch of 2 mm, and the third plane (collection plane) is a PCB with horizontal strips with a width of 1 mm and a pitch of 2 mm; the chamber has a total of 329 channels. In the beginning of the run a maximal drift field of 1.5 kV/cm was applied and had to be reduced later to to 0.3 kV/cm because of HV breakdowns. The Lorentz angle for a drift field of 0.5 kV/cm and a B-field of 0.5 T was estimated to be $\approx 1.7°$.
For initial tests without magnetic field, a coincidence of the scintillators was used to trigger on through-going muons (trigger rate 0.55 Hz). To trigger on stopping muons, the scintillators on top of the cryostat in the bore hole were used, yielding the time t_0 of the event needed to determine the drift time, together with the analog sum of 32 channels of the TPC; the rate was about 1/min. About 30'400 events were collected and visually scanned, and a small sample of 15 δ-electrons and 8 decay positrons from stopped muons were selected for a first analysis [10]. This represents a highly biased sample of well measurable events fully contained in the chamber. The tracks were reconstructed in 3D and their momentum and kinetic energy were calculated from the magnetic bending and the summed energy loss along the track. Fig. 3 shows on the left side the comparison of the p_t obtained from the magnetic bending and from the energy measurement; on the right side is the measured kinetic energy plotted versus the total track length.

2. Investigation of high temperature superconductors in liquid argon and nitrogen

A very interesting option to magnetize a LAr TPC would be to build a high temperature superconducting (HTS) solenoid directly in the LAr cryostat of the detector. Since the manufacturers deliver data on the temperature dependence of the properties of their commercial HTS cables only up to LN_2 temperature (77 K), we performed a small R&D program to investigate the performance of different HTS cables also at LAr temperature (87 K) [11]. We tested BSCCO (first generation HTS cable) and YBCO (second generation) from American Superconductors AMSC[2] and SuperPower Inc.[3]. Table 1 summarizes some properties of the tested cables.

We measured the critical current I_c in LN_2 and LAr as a function of an external magnetic field applied parallel (in the direction of the width of the cable) and perpendicular to the HTS cable. Here, the critical current I_c is defined as the current, for which the voltage drop in the

[2] www.amsc.com
[3] www.superpower-inc.com

AMSC	Width	Thickness	Critical temp.
BSCCO	4 mm	0.4 mm	110 K
YBCO	4.3 mm	0.25 mm	90 K
SuperPower			
YBCO	4 mm	0.1 mm	90 K

Table 1. Properties of the tested HTS cables.

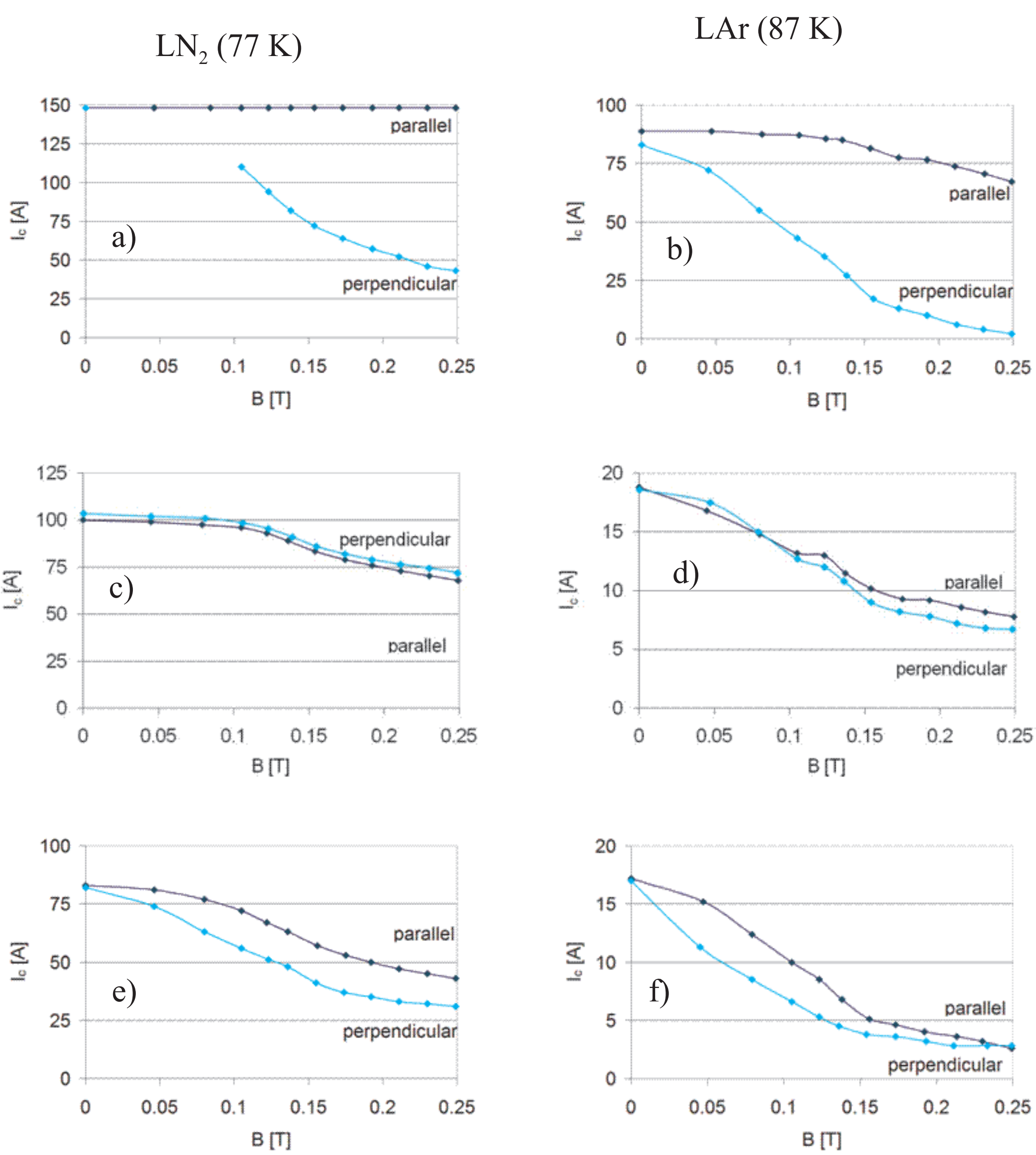

Figure 4. Measured critical current I_c for the three tested HTS cables as a function of the applied parallel and perpendicular magnetic fields. Left column: measurements in LN_2 at 77 K, right column: measurements in LAr at 87 K. a) and b) BSCCO cable from AMSC, c) and d) YBCO cable from AMSC, e) and f) YBCO cable from SuperPower Inc.

cable reaches $1\,\mu\,\mathrm{V/cm}$. Fig. 4 shows, that in LAr the critical current is already substantially reduced compared to the value measured in LN_2, in particular for the second generation YBCO cables.

After testing the cables, we built a small prototype HTS solenoid with about 100 m of the AMSC BSCCO cable [12]. The solenoid shown in Fig. 5 consists of four so-called pancakes with 25 (on average) windings. It has a total length of 130 mm, including the iron end plates and copper spacers and iron shielding rings between the pancakes. The average diameter of the windings was 230 mm and the bore hole was 210 mm. The iron shielding rings was inserted between the pancakes to suppress the perpendicular B-field component at the innermost coil windings. In LN_2 a maximal B-field of 0.2 T was achieved at I = 145 A and in LAr it was 0.11 T at I = 80 A.

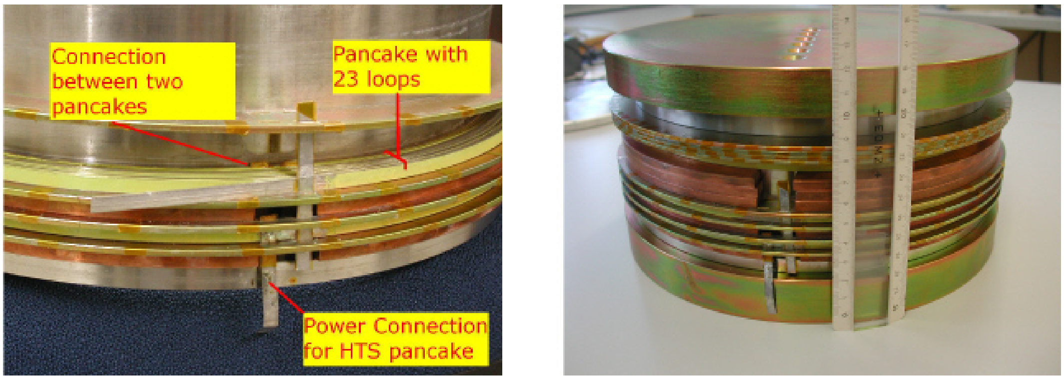

Figure 5. Left: Connections of the pancakes of the HTS solenoid. Right: The complete solenoid.

References

[1] C. Rubbia, *The Liquid-Argon Time projection Chamber: a new concept for Neutrino Detector*, CERN-EP/77-08, (1977).
[2] S. Amerio et al., Nucl. Instr. and Meth. A 527 (2004) 329.
[3] M. Campanelli, A. Bueno and A. Rubbia, *Optimization Studies for CP- and T-violation*, Nucl. Instr. and Meth. A 503 (2003) 133.
[4] A. Bueno, M. Campanelli, S. Navas-Concha and A. Rubbia, *On the energy and baseline optimization to study effects related to the delta-phase (CP-/T-violation) in neutrino oscillations at a neutrino factory*, Nucl. Phys. B 631 (2002) 239.
[5] A. Rubbia, *Neutrino factories: Detector concepts for studies of CP and T violation effects in neutrino oscillations*, arXiv:hep-ph/0106088. Appeared in *Proceedings of the 9th International Symposium on Neutrino Telescopes, Venice, Italy, March 2001.*
[6] A. Bueno, M. Campanelli and A. Rubbia, *Physics potential at a neutrino factory: Can we benefit from more than just detecting muons?*, Nucl. Phys. B 589 (2000) 577, arXiv:hep-ph/0005007.
[7] M. Laffranchi, PhD thesis No. 16002, ETH Zurich, 2005.
[8] A. Badertscher et al., New J. of Phys. 7 (2005) 63.
[9] A. Badertscher et al., Nucl. Instr. and Meth. A 555 (2005) 294.
[10] A. Müller, Diploma thesis, ETH Zurich, 2005.
[11] Th. Strauss, PhD thesis, ETH Zurich, 2010.
[12] Th. Strauss, Diploma thesis, ETH Zurich and Humboldt-Universität Berlin, March 2006.